Partial Combustion of Fuel Oil with Oxygen and Application to Smelting Iron Ore

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Much interest in alternative smelting processes based on cheaper fuels than metallurgical coke has developed during the past decade. Many processes have been developed, however, none of these processes have proven competitive with the blast furnace in the United States. In this context, it was decided to study a proposed smelting process in which all the reducing gases and heat for smelting come from the partial combustion of fuel oil and/or pulverized coal with oxygen at the bottom of a shaft reactor. Some anticipated advantages of such a process over the blast furnace are elimination of the stoves and associated equipment for heating the blast, reduction or elimination of coke requirements, and production of hot metal at much higher rates than are presently obtained with blast furnaces.

Preliminary heat and material balances indicated that the proposed process is feasible. Several important factors associated with the operation of a partial-combustion burner and with the operation of the reactor, however, could not be investigated theoretically. With respect to burner operation, the extent of conversion of fuel oil with oxygen to CO and H_2, the nature of any solid carbon formed during partial combustion, and the stability of combustion were the most important factors to be determined experimentally. As for the operation of the reactor, it was not known whether smooth flow of materials and effective contact between gases and solids could be achieved without the leavening action provided by coke in the blast furnace. In addition, it was not known whether sufficient residence time can be obtained to complete reduction at the high throughput rates assumed in the theoretical analysis.

Theoretical and Practical Considerations

Figure 1 shows that the theoretical flame temperature for stoichiometric partial combustion of No. 6 fuel oil with oxygen to produce CO and H_2 is 3375 F. With 10 percent excess oxygen, the flame temperature would be approximately 4000 F. If 10 percent ungasified carbon were formed with stoichiometric oxygen, the flame temperature would be approximately 3700 F. Thus, the required temperatures for smelting iron oxide are theoretically attainable. Whether they could be obtained in practice, however, remained to be determined.

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In most commercial applications, combustion refers to the rapid oxidation of a material with the evolution of large quantities of heat. Usually, the specific rates of the chemical reactions occurring in the combustion process are so rapid that physical transport phenomena control the rate of combustion. These physical characteristics are directly related to the degree of mixing of the reactants. A device known as a burner is used to prepare and introduce the reactants into the reaction zone in such a manner as to produce an efficient rate of combustion.

The most effective burner for high-intensity combustion would mix the fuel with the oxygen before introduction into the combustion chamber. Many gas burners premix all or most of the air or oxygen needed for combustion with the gas and produce a high-temperature flame. A bunsen burner premixes only as much air as can be aspirated; its flame is therefore not as hot nor as well defined as the flame of burners utilizing completely premixed air and fuel because some of the air needed for combustion must come from the surroundings of the flame. When all aspirated air to the burner is shut off, the flame becomes long and poorly defined because all the air must mix with the gas by diffusional means, a much slower method of mixing.

Because liquid fuels cannot be appreciably premixed before burning, the rate of combustion is controlled by the mixing in the combustion zone. To facilitate combustion, liquid fuels are usually injected into the combustion zone through an atomizing nozzle. There are three types of atomizers: (1) pneumatic nozzles that use air, steam, or some other gas to atomize the liquid; (2) high-pressure nozzles that force the liquid through a small orifice; and (3) mechanical devices that use rotating discs to break up the liquid. The energy used to atomize the liquid is greatest for the first type, which usually produces a spray of finer droplets than the other types.

There are two common methods for providing good mixing of the reactants in the combustion zone. The first is direct impingement of the fuel and air jets, each introduced into the combustion zone at different angles. In the second method, opposite radial velocity components are imparted to the two streams by the use of vanes in each injector tube. For efficient operation, most burners are designed to use one of these methods.

Liquid fuels such as fuel oil burn according to the following simplified mechanisms:

1. The volatile components in the oil are vaporized
2. The vapors react with oxygen, evolving sufficient heat to propagate the combustion. If sufficient oxygen is not immediately available to react with all the carbon in the vaporized portion of the fuel, the unreacted hydrocarbons will crack to form solid carbon particles and hydrogen.

3. The nonvolatile matter (primarily solid carbon) is burned. This carbon, as well as any carbon formed by the cracking of hydrocarbons, is consumed by a relatively slow solid-gas reaction mechanism.

Previous workers have found that the reaction time of the solid residue is as much as 10 times that of the volatile matter.[1,2)*] These experiments were performed in an atmosphere containing an excess of oxygen. The increase in burning time for cases in which there is a deficiency of oxygen, such as in a partial-combustion process, would probably be even greater. It is therefore desirable to minimize the amount of solid carbon formed during primary combustion. The minimum solid carbon would be comprised of oil residue, with none being formed by cracking of volatiles.

When atomization is good, the rates of evaporation of volatiles and reaction of volatiles with oxygen are very rapid. Therefore, to prevent any of the volatiles from cracking, oxygen must be made available before the hydrocarbon vapors reach the cracking temperature. Because the oxygen and oil are not premixed, very rapid mixing must occur as soon as these reactants enter the combustion chamber. Because this mixing can only occur by eddy and molecular diffusion, it is evident that mixing is normally the limiting factor in establishing the rate of combustion. This conclusion is based on work done under conditions of complete combustion, and is probably even more restrictive under conditions of partial combustion.

Description of Burner System and Operating Procedure

In view of the theoretical and practical considerations, it was apparent that the combustion chamber would have to be constructed of a refractory capable of withstanding very high temperatures in both oxidizing and reducing atmospheres. It was also apparent that because of the small volume of oxygen needed per unit of fuel compared with a complete combustion burner operating on air — only 1/16 the volume of reacting gas and 1/3 the oxygen is required for partial combustion using oxygen — satisfactory mixing of the reactants would be considerably more difficult. If sufficient mixing were not provided, flame stability would decrease, localized excessive temperatures would result, and large quantities of solid carbon would be formed that would greatly increase the time needed to complete the gasification process; additional combustion-chamber volume would be needed to produce a given amount of reducing gas.

These factors were considered in selecting a commercial fuel-oil burner that was adaptable for use as a partial-combustion burner. An air-atomizing vortex burner was procured that fulfilled these requirements. In addition to the fine atomization obtainable with this burner, the main oxygen stream had a counterclockwise motion imparted to it by

*See References

means of vanes in the windbox. This arrangement provided one of the most efficient means available in a commercial burner for mixing the fuel oil and oxygen.

Figure 2 shows details of the oil-injection nozzle, the center cone, the windbox vane detail and the oxygen nozzle comprising the essential parts of the burner, Figure 3 is a section view of the assembled burner, and Figure 4 is a section view of the atmospheric test chamber.

Figure 5 shows a schematic piping diagram for the burners. The oil rate is obtained by measuring the change in weight of the oil-supply barrel with time. A positive-displacement pump transports the oil against a constant delivery pressure maintained by the pressure-regulating valve. The oil rate is controlled manually with an air-operated control valve. The pressure switches are connected to an annunciator that warns when the oil pressure deviates from a preset range; a solenoid valve in the line enables the oil flow to be stopped rapidly.

The primary oxygen flow is measured by a calibrated rotameter and is controlled manually by a needle valve. The pressure switch in the oxygen line is connected to the annunciator panel to indicate a low-pressure oxygen supply; a solenoid valve enables the oxygen flow to be stopped rapidly.

The system was piped to provide for either air or oxygen atomization. The atomizing flow rate was measured by a calibrated rotamete Electric resistance heaters were installed in both the primary oxygen and the atomizing lines so that these streams could be heated during cold-weather operation.

Figure 6 shows a schematic diagram of the electrical wiring for one burner system. The pressure switches are connected to an annunciator that rings an alarm and flashes a light when any of the supply pressures deviate from a preset range. The solenoid valve switches are arranged so that the atomizing gas flow has to be started before the oil and oxygen to provide a safe start-up.

To become familiar with the operating characteristics of the burner, tests were made using only air and No. 6 fuel oil. A typical chemical analysis of the No. 6 fuel oil is shown in Table I. Although the burner performed as expected under complete-combustion conditions, burner operation became unstable as the air rate was decreased. Apparently, the heat released per unit volume of fuel became so low that the flame could not propagate itself effectively. The next step was to use oxygen for primary combustion gas and air for atomization.

During these initial tests using oxygen, the burner was being fired at 40 to 50 pounds of oil per hour using zero to 10 percent excess oxygen, and with an atomizing pressure of 40 to 60 psig. The pressure drop across the windbox of the burner (a measure of the energy

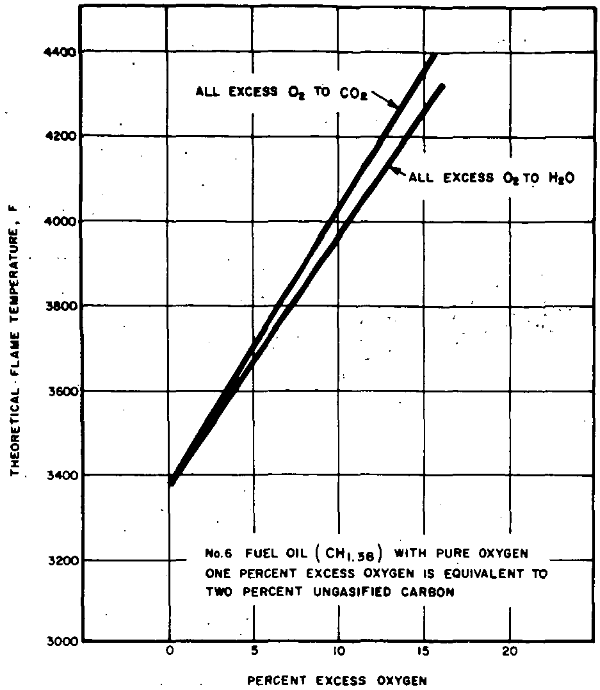

FIGURE I THEORETICAL FLAME TEMPERATURES FOR PARTIAL COMBUSTION OF BUNKER C FUEL OIL VERSUS EXCESS OXYGEN

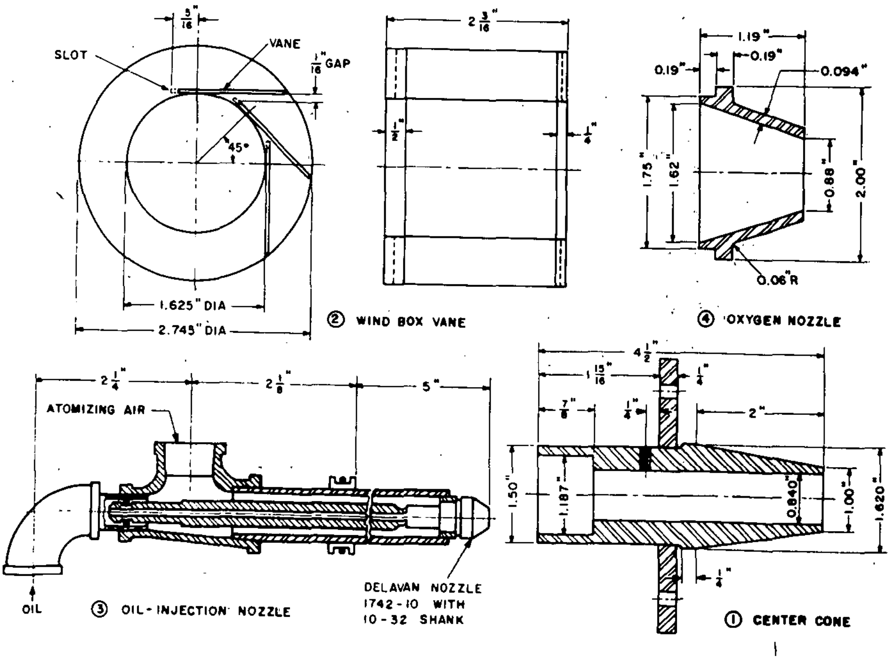

FIGURE 2 DETAILS OF BURNER PARTS

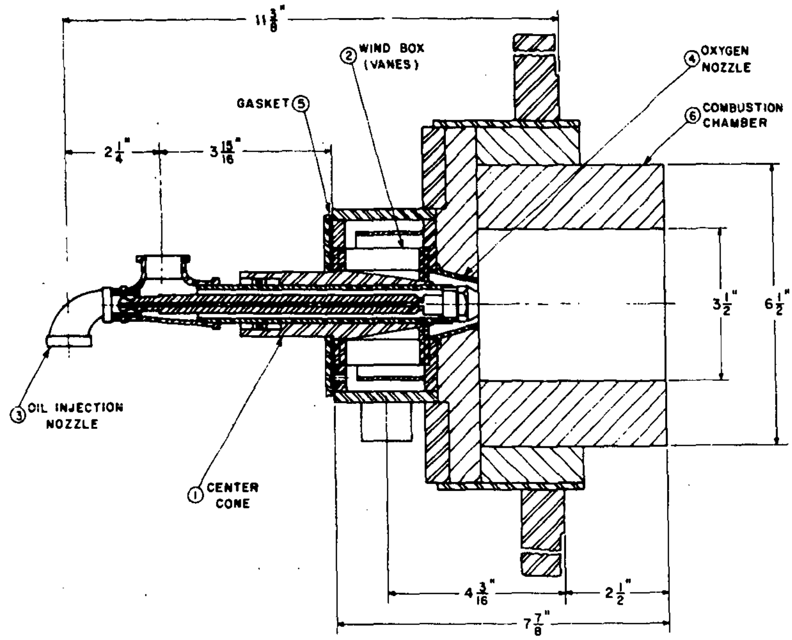

FIGURE 3 SECTION VIEW OF ASSEMBLED BURNER

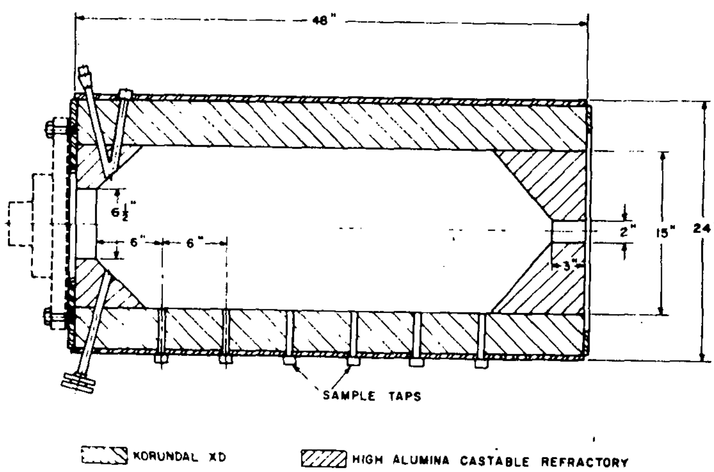

FIGURE 4 ATMOSPHERIC TEST CHAMBER

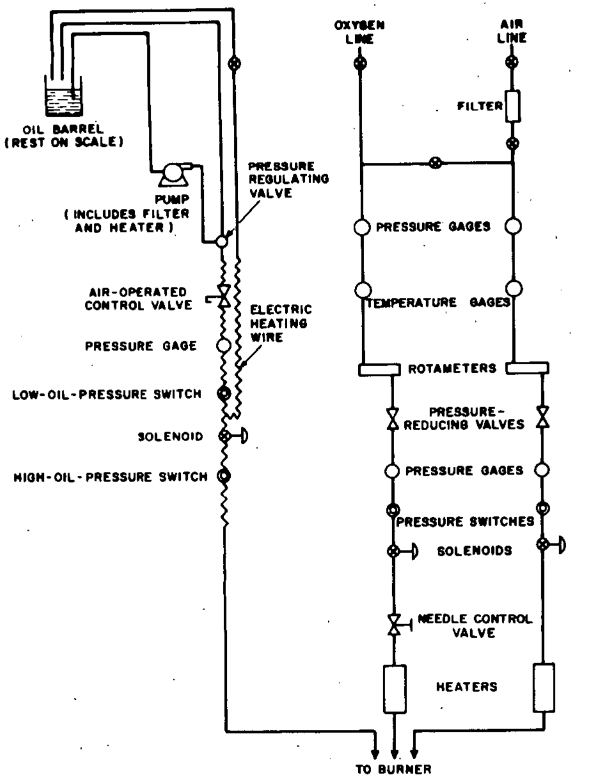

FIGURE 5 PIPING DIAGRAM FOR PARTIAL-COMBUSTION BURNER

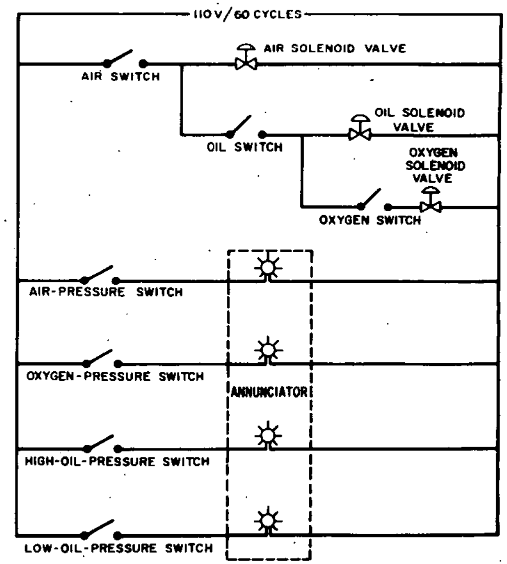

FIGURE 6 SCHEMATIC ELECTRICAL DIAGRAM FOR PARTIAL-COMBUSTION BURNER SYSTEM

released to the gas stream for mixing the reactants) was approximately two inches of water. In addition to poor conversions (the fraction of carbon in the oil that is gasified) during these studies, hard carbon would rapidly build up in the combustion chamber. This would direct the flame back onto the burner tip and force a shutdown. The hard carbon build-up was attributed to a combination of coarse atomization and lack of turbulence in the chamber, and probably occurred when oil droplets impinged on the hot refractory surface. It was obvious that finer atomization and increased turbulence in the chamber were necessary to prevent formation of hard carbon. Finer atomization was obtained by increasing the atomizing pressure. Increased turbulence in the combustion chamber was obtained by increasing the pressure drop across the windbox. This was done by decreasing the gap between the vanes in the windbox (part 2, Figure 2) from 1/16 inch to 1/64 inch, and decreasing the diameter of the oxygen nozzle (part 4, Figure 2) from 1 inch to 0.88 inch. These changes eliminated the hard-carbon build-up, but did not appreciably improve conversion. It was later determined that erosion of the nozzle tip had been the major cause of coarse atomization at 40 psig atomizing pressure, and that satisfactory operation at this atomizing pressure was possible with a new nozzle. When these changes were made it was possible to operate the burner continuously for extended periods (at least 8 hours) and a test program was begun to determine the operating conditions for most efficient fuel conversion. The independent variables chosen were oil rate, percent excess oxygen, and atomizing pressure. The range of conditions studied are listed in Table II.

Testing began when the walls of the atmospheric test chamber became incandescent. The independent variables chosen for the test were established and 30 minutes was allowed for attainment of steady-state conditions. Two gas samples, one 3 feet and one 1.5 feet from the burner nozzle, were then taken from the inside wall of the test chamber using an uncooled 1/4-inch-diameter stainless-steel tube. These samples were analyzed by gas chromatography for CO, CO_2, H_2, and N_2. Several samples were analyzed with a mass spectrometer to determine the quantities of other hydrocarbons (such as CH_4, C_2H_2, and C_2H_6) being formed. The mass-spectrometer results indicated that less than 1.5 percent of the total product gas was made up of constituents other than CO, CO_2, H_2, and N_2; the chromatograph results were therefore used to calculate material balances. Elemental balances for hydrogen, carbon, and oxygen were used to calculate the quantities of soot and water vapor, and the total moles of dry gas formed. A check on the consistency of the data was possible by a nitrogen balance.

Analysis of the data from this program showed that the burner was not very efficient (cf.results below). Because it was believed that the original nozzle was the major source of trouble, studies were also made using a special spray nozzle designed for operation over a wider range of fuel rates. Figure 7 is a detailed drawing of this nozzle.

Results of Burner Tests

Most commercial burner systems are operated under complete combustion conditions and efficiencies are usually expressed as thermal output per unit of fuel consumed. In the case of partial-combustion systems, it is more meaningful to consider the degree of gasification of the fuel. In the present application this type of burner has a dual purpose — to produce reducing gas and to produce sufficient heat to melt the solid products in a smelting operation. Thus, the formation of a small amount of CO_2 and H_2O is not necessarily detrimental to the performance of the process. However, it is possible that any ungasified carbon leaving the combustion zone will remain as such in its passage through the reactor and thus represent an unrecoverable loss of energy. In the analysis of the present data, therefore, the percent excess oxygen was considered as the independent variable, the percent ungasified carbon as the dependent variable, and the fuel rate, atomizing pressure, and sampling location as the parameters.

Figure 8 shows the data obtained inside the test chamber 3.0 feet and 1.5 feet from the original nozzle tip while operating at an oil rate of 45 to 50 pounds per hour; atomizing pressure is the parameter. It is clear that atomizing pressure has little effect on fuel conversion, probably because atomizing pressure has little effect on the mixing of the oil and oxygen. This would not be true at very low atomizing pressures (up to about 20 psig) where atomization is coarse and the rate of evaporation becomes a limiting step in the burning process. It is concluded that for all the atomizing pressures studied, the fineness of atomization was sufficient to maintain an evaporation rate greater than the reactant mixing rate, thereby making burner performance independent of atomizing pressure. This result held at the higher oil rates and also for the special spray nozzle.

Figure 9 represents the data when considering the fuel rate as a parameter. It is clear that fuel rate has no significant effect on conversion. This result is probably due to the fact that the decreased residence time for the higher fuel rates is compensated for by increased turbulence and concomitant improvement in mixing.

Figure 10 is a plot of percent ungasified carbon versus percent excess oxygen for comparable data using the original nozzle and the special spray nozzle. Better conversions were obtained with the special spray nozzle.

In all cases, better conversions were obtained 3 feet from the nozzle tip than 1.5 feet from the tip. This distance would be expected to directly affect the conversion since the extent of mixing is a function of that distance (in terms of increased residence time). In addition, the burning times of the solid residue and soot are probably comparable to the residence time of the gas in the test chamber. Thus, even with perfect mixing, a difference in conversion would exist between the two sampling locations.

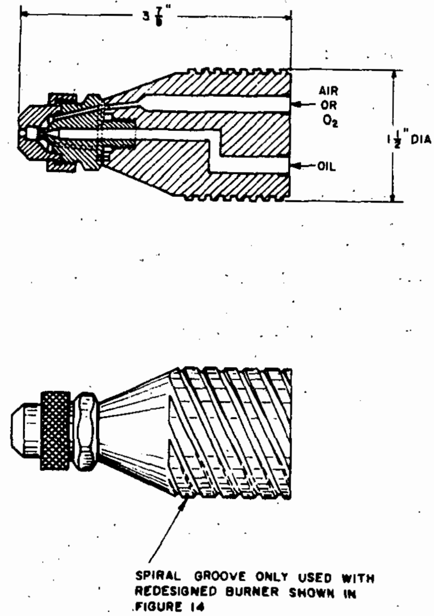

FIGURE 7 SPECIAL SPRAY OIL INJECTION NOZZLE

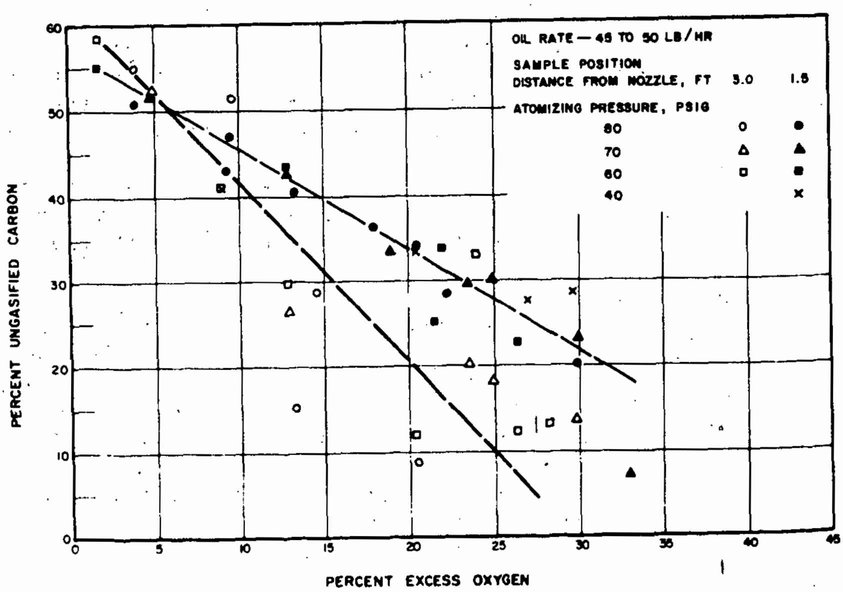

FIGURE 8 EFFECT OF ATOMIZING PRESSURE AND SAMPLING POSITION—ORIGINAL NOZZLE

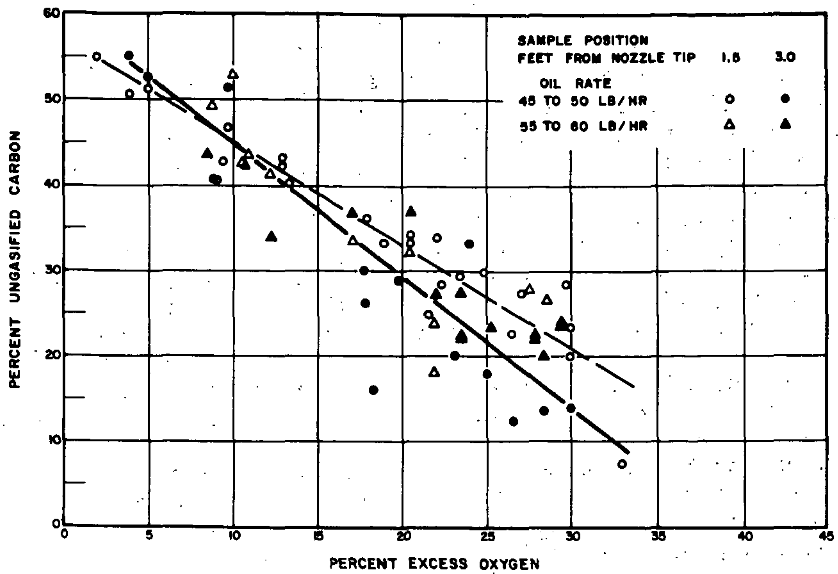

FIGURE 9 EFFECT OF FUEL RATE AND SAMPLING POSITION—ORIGINAL NOZZLE

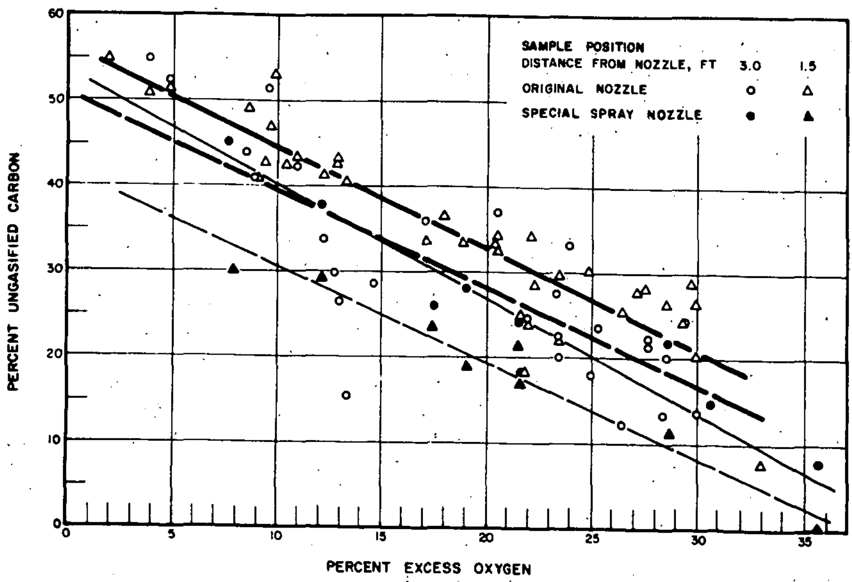

FIGURE 10 EFFECT OF SAMPLING POSITION AND NOZZLE DESIGN

Under all conditions, with less than 15 percent excess oxygen, the ungasified carbon was greater than 20 percent. With ideal mixing of the reactants, any ungasified carbon would represent solid carbon from nonvolatile matter in the oil and not from cracking of the volatiles. However, the oil contained greater than 90 percent volatile matter. Thus, at least half of the ungasified carbon formed came from cracking of volatiles. This is so because, with perfect mixing, the volatiles would probably burn as rapidly as they evaporate,[5] and the quantity of ungasified carbon would be 10 percent or less, depending on the sampling position and burning time of the residue.

The results of other work done on evaporation rates and combustion rates of fuel droplets[3] indicate that 0.3 to 0.6 seconds (the average residence time available for a drop to react in our apparatus) is far in excess of the time needed to evaporate and burn the volatile matter. It is therefore believed that the present system could, with perfect mixing of the reactants, gasify all carbon contained in the volatile matter and produce a product gas containing less than 10 percent ungasified carbon. Because gasification of solid residue is about 10 times slower than gasification of volatiles, conversions better than 90 percent would require longer residence time than can be obtained in the test chamber. In any event, the technical feasibility of the proposed smelting process should not be restricted by the low conversions obtained in the test chamber. This conclusion is based on the knowledge that, even when operating with 20 percent excess oxygen, the gas produced will be reducing to FeO. Table III shows the results of a representative run and a comparison of the actual CO_2/CO and H_2O/H_2 ratios with the equilibrium ratios for 2000 F. Although the H_2O/H_2 ratio is only moderately reducing, the CO_2/CO ratio is substantially reducing to FeO. In addition, it must be remembered that the operation of the proposed process will provide enough solid carbon in the burden to reduce these complete combustion products and for solution in the hot metal produced.

Pilot-Plant Design

Figure 11 is a picture of the pilot plant comprising of a shaft reactor, a double-hopper arrangement for feeding solids, an off-gas system, and a control room that houses most of the equipment for operating the burners. Figure 12 shows a cross-sectional diagram of the reactor, which is constructed in four sections: the hearth, the lower stack (containing two diametrically opposed burner mounting assemblies), the upper stack, and the top head. The reactor shaft is a 10-foot straight section, 1 foot in diameter, that flares to 2 feet where it is attached to the hearth. The hearth is 2 feet in diameter and 2 feet high. The reactor is lined with 18 inches of refractory material; the inner face of high-alumina brick is backed by a layer of fire-clay brick and a layer of low-conductivity castable refractory. The refractory is separated from the steel shell by a one-inch layer of asbestos block insulation.

Eight flanged ports for measuring stack temperatures and pressures, and for obtaining gas samples are located at four levels of the stack.

Table I

Chemical Analysis of No. 6 Fuel Oil

	Weight Percent
Carbon	87.24
Hydrogen	11.19
Oxygen	0.69
Nitrogen	0.27
Sulfur	0.59
Ash	0.02
Volatile Matter	94.56
Fixed Carbon	5.42

Table II

Range of Variables Studied in the Test Chamber

Oil Rate, lb/hr	Atomizing Pressure, psig	Excess Oxygen, %
48	80, 70, 60, 40	0 to 30
58	80, 70, 60	0 to 30

Table III

Results of Representative Burner Operation with No. 6 Fuel Oil

Test Number 181

Oil Rate	56.4 lb/hr
Atomizing Air Rate	3.39 scfm*
Primary Oxygen Rate	15.05 scfm
Excess Oxygen	21.6%
Ungasified Carbon	17.0%

Product Gas Analysis, Mole Percent

CO_2	5.5
CO	43.1
H_2	27.7
H_2O	17.2
N_2	6.5

$\frac{CO_2}{CO} = 0.128$ $\qquad$ $\frac{H_2O}{H_2} = 0.621$

$\left(\frac{CO_2}{CO}\right)_{eq} = 0.390$ $\qquad$ $\left(\frac{H_2O}{H_2}\right)_{eq} = 0.675$

Equilibrium ratios are for 2000 F

* 70 F and 1 atm

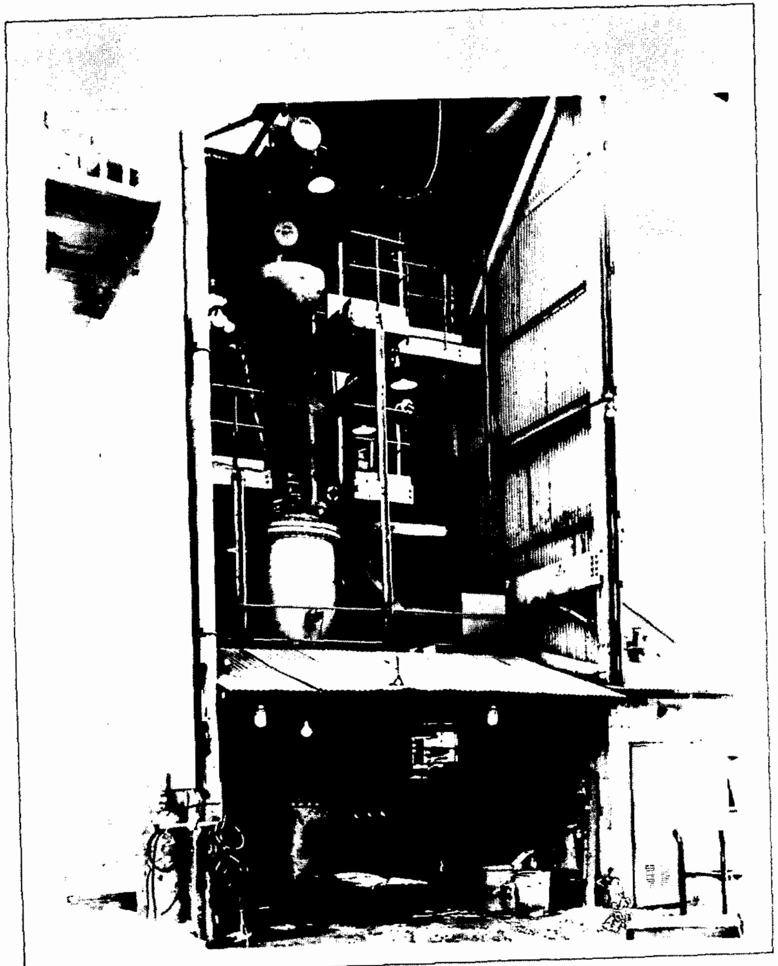

Figure 11. Picture of Pilot Plant

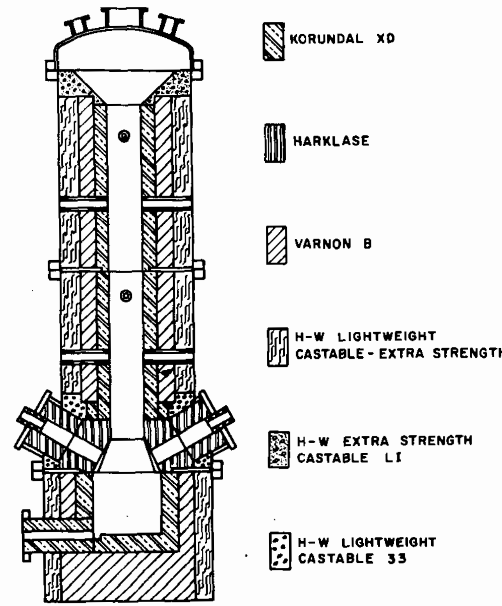

FIGURE 12 CROSS-SECTION OF FUEL-OIL OXYGEN SMELTING REACTOR

Partial-Combustion Studies in Pilot Plant

In the atmospheric test chamber the combustion efficiency (expressed as the percent of carbon gasified) was low; at least 15 percent excess oxygen (over the theoretical oxygen for combustion to CO and H_2) was needed for 80 percent gasification. These low conversions were caused by the low residence times and high heat losses in the test chamber. In addition, it was learned that the oil rate and the atomizing pressure had very little effect on the combustion efficiency. The percent excess oxygen and the residence time were the only variables that significantly affected combustion efficiency; gasification increased with increased excess oxygen and further distance from the burner.

A test program was run in the pilot plant to verify and extend the results obtained in the atmospheric test chamber. The ranges of the independent operating variables are listed in Table IV. Each burner test consisted of two hours of operation at the test conditions. A set of gas samples (bottom, top, and off-gas) was taken after one hour and after two hours of operation. Material balances were then calculated from the operating data and chemical analysis of the samples.

The results are plotted in Figure 13 as percent ungasified carbon versus percent excess oxygen for the special spray nozzle and for the original nozzle. The results obtained in the atmospheric test chamber are also shown for comparison. Conversions in the reactor were much better than in the test chamber because of the longer residence time and higher temperatures. Conversions for the special spray nozzle were significantly better than for the original nozzle. As in the atmospheric-test-chamber operation, there was no significant effect of the atomizing pressure or the oil rate on the burner performance.

There is considerable scatter in the data in Figure 13. This scatter is attributed primarily to poor gas mixing and distribution and to the fact that the material balances are very sensitive to small differences in nitrogen concentration. It is therefore instructive to study the results of a 24-hour test with constant-burner operating conditions. Gas samples were taken at the bottom and top of the reactor, and from the off-gas line every hour during this run. The other operating variables were recorded periodically so that an average material balance could be calculated for the day of operation. The material flows were held constant during the whole operation; there was less than 5 percent variation in any of the flows. The average operating data and results are presented in Table V. There was more ungasified carbon at the bottom of the reactor than at the top or in the off-gas. This result was expected because the studies made in the atmospheric test chamber showed that gasification increased with longer residence times. The increase in ungasified carbon between the top and the off-gas sections was unexpected and may be due to carbon deposition in this part of the system. Most of the short-duration tests in the reactor showed this same trend; there was a slightly higher amount of ungasified

Table IV

Operating Ranges for Burner Test Program

Excess Oxygen, %	- 5 to 25
Oil Rate, lb/hr	40 to 90
Atomizing Pressure, psig	40 to 70
Sampling Position	Bottom of Reactor Top of Reactor Off-Gas System

Table V

Summary of Average Operating Conditions and Results of 24-Hour Burner Test (2 Burners)

Oil Rate	73.4 lb/hr/burner
Atomizing Air Rate	6.57 scfm/burner
Primary Oxygen Rate	18.23 scfm/burner
Atomizing Pressure	70 psig
Percent Excess Oxygen	17.7

Dry-Gas Analyses, Vol. %	Bottom	Top	Off-Gas
CO	52.6	51.9	52.3
CO_2	4.1	3.2	3.2
H_2	34.6	36.4	35.8
N_2	8.7	8.5	8.7

Wet-Gas Analyses, Vol. %	Bottom	Top	Off-Gas
CO	46.4	49.6	48.9
CO_2	3.5	3.1	3.0
H_2	30.5	34.8	33.5
H_2O	11.9	4.4	6.3
N_2	7.7	8.1	8.2
Percent Ungasified C	10.0	-3.1	0.1

Nitrogen-Balance Error $\sim$ 0.7%
(Independent Data Check)

carbon in the off-gas line than at the top of the reactor and conversions at both of these locations were much higher than at the bottom of the reactor.

These results of the burner tests run with an unfilled reactor are summarized as follows:

1. Burner rates were varied from 40 to 90 pounds of oil per hour with no significant difference in burner performance.

2. Atomizing pressures were varied from 40 to 70 psig with no significant difference in burner performance.

3. Stable burner operation was obtained from minus 10 to plus 25 percent excess oxygen.

4. The burners could be operated continuously for at least 5 days with no noticeable nozzle erosion.

5. Combustion chambers cast from high-purity magnesium oxide and burned at about 2800 F performed very well.

Burner Redesign

Several problems associated with burner design were brought into focus during the reactor-test program. First, in the original design the combustion chamber was located very close to the outside mounting flange. Heat losses were therefore unnecessarily high and the mounting flange was susceptible to high-temperature damage. In addition, removal of the burner for inspection invariably broke the combustion chamber, and this meant a complete rebuilding of the burner. And finally, the inspection and replacement of burner nozzles that plugged during operation was time consuming.

Figure 14 shows a drawing of the revised burner design. This design eliminates all the problems discussed above without sacrificing any features of the original design that are necessary for efficient combustion. The combustion chamber was relocated closer to the stack, thereby minimizing heat losses and protecting the mounting. The unitized system could be quickly removed and replaced if any trouble occurred; also, the system retained the vortex action of the primary oxygen input.

Operation of Pilot Plant as a Steel Melter

After the operation of redesigned partial-combustion burners was demonstrated to be satisfactory with a coke-filled stack, it was planned to study the operation of the system as a steel melter. Steel punchings 1 inch in diameter and 3/8-inch high and small coke were used as the burden. The pilot plant was operated successfully as a melter for four consecutive days (including one day for start-up). Table VI presents a summary of the operating conditions and results. The oil rate during

Table VI

Summary of Operating Conditions and Results for Melting Operation

	Period 1	Period 2
Duration, hours	42	24
Oil Rate, lb/hr	100	100
Atomizing Air Flow, scfh	720	720
Atomizing Pressure, psig	~70	~70
Primary Oxygen Flow, scfh	1530	1530 (100% O_2)
Excess Oxygen, %	~20	~20
Theoretical Flame Temperature, F	4275	4275
Burden Ratio, lb coke/lb steel	0.25	0.11
Approximate Casting Rate, lb/hr	85	160

Oil Analysis, wt %

C	87.03
H	11.09
N	0.29
O	0.95
S	0.59

Metal Analysis, wt %

	Charge	Product
Fe	98.9	~98
Si	0.13	<0.01 to 0.29
S	0.031	0.11 to 0.18
C	0.37	0.2 to 2.6

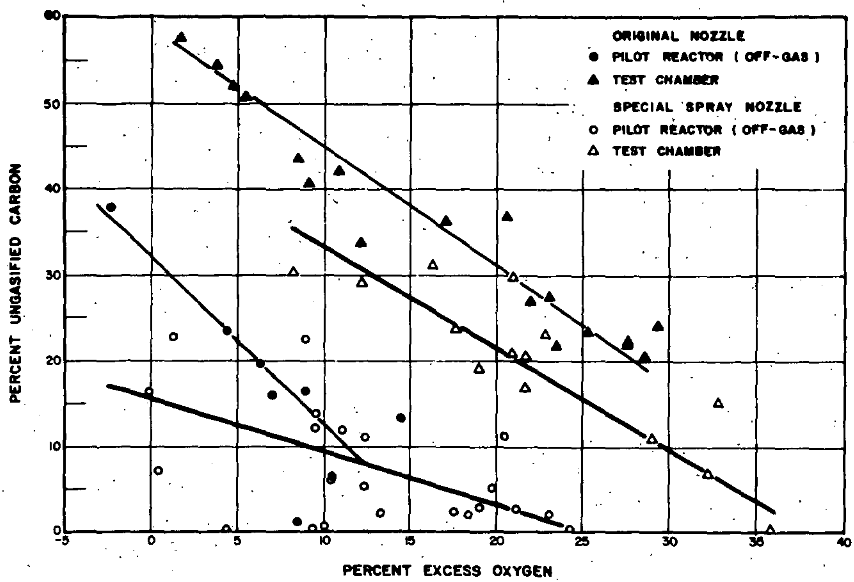

FIGURE 13 CONVERSION VERSUS EXCESS OXYGEN

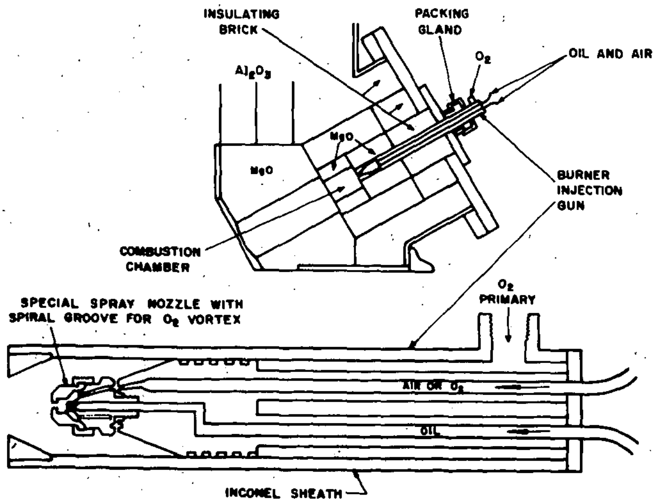

FIGURE 14 SCHEMATIC DIAGRAM OF NEW BURNER DESIGN

this operation was 100 lb/hr (for two burners); the burners were operated with about 20 percent excess oxygen, and the atomizing air pressure was 70 psig. The burden movement was smooth, and hot metal was successfully removed from the hearth during this operation. During the first day and a half of melting operation, the coke-to-steel weight ratio was 0.25 and the melting rate was 85 lb/hr. During the rest of this period, the coke-to-steel ratio was decreased to 0.11 and the melting rate was 160 lb/hr. Inspection of the system after the shutdown showed that the reactor and the burner guns were in excellent condition.

Operation of Pilot Plant as a Smelter

The pilot plant was operated as a smelter with a burden of 90 percent self-fluxing sinter and 10 percent coke. Table VII presents a summary of the steady-state operating conditions and results. About 12 hours after the first charge, small amounts of molten metal were tapped. The rate of burden movement gradually increased for the next 7 hours until it reached a steady state. For the next 13 hours operation was very good. The charging rate averaged 340 lb/hr and was very steady. Casts were made every two hours and little difficulty was encountered in getting the material to flow. Operation of the burner was very smooth. The operation ended when the burden hung at the base of the feed hopper and then slipped 1-1/2 hours later, thereby charging 500 pounds of cold material into the stack. This plugged the stack and caused a complete shutdown. Considerable damage was done to the refractory in the hearth and lower stack.

As shown in Table VII, the total carbon rate was 1300 lb/THM, of which the coke supplied about 300 lb/THM, and the fuel oil 1010 lb/THM. This low total fuel and coke ratio is very encouraging because of the small size of the pilot reactor, which inherently has relatively large heat losses. Also encouraging was the fact that burden movement was excellent in spite of the low coke ratio, and there were no indications that an even lower coke ratio would not work well.

Many serious problems were encountered during the operation of the pilot plant, primarily with the construction and performance of the refractories around the burners. There were many failures; however, it is believed that these failures can be attributed to the small size of the plant. Because the plant has a relatively high ratio of surface area to volume, heat losses were high and the burners must be operated at higher temperature (higher excess oxygen) to compensate. In a larger plant the operating conditions would not be as severe. In any event, the results indicate, at least from the standpoint of burden movement and permeability, that very high "fuel-injection" levels — approaching "cokeless" operation — can be achieved in shaft processes for smelting iron ore.

Table VII

Summary of Operating Conditions and Results
For Smelting of Self-Fluxing Sinter

A. Raw Material Analyses, Weight Percent

Coke		Sinter		No. 6 Fuel Oil	
C	88.26	Fe_T	60.52	C	87.36
H	1.82	O	24.50	H	10.92
N	0.96	SiO_2	5.72	O	0.87
S	0.75	Al_2O_3	1.02	Ash	0.012
O	2.55	CaO	6.93	S	0.55
Ash	5.66	MgO	0.89		
Moisture	8.53	TiO_2	0.15		
		C	0.15		
		S	0.009		
		M_m	0.093		
		P	0.054		
		FeO	11.91		
		Fe_2O_3	73.29		

Combustion Oxygen 99.5 percent O_2

B. Input Data

No. 6 Fuel Oil, lb/hr	119.1	
Coke, lb/hr	37.8	
Sinter, lb/hr	340.0	
Atomizing Air, moles/hr	1.73	(11.16 scfm)
Primary Oxygen, moles/hr	4.78	(30.82 scfm)

C. Output Data

Average Off-Gas Analysis (approximate volume %, based on 3 samples), Dry Basis

CO	49.0
CO_2	12.7
H_2	28.25
N_2	9.9

Material Balance - Based on N_2

Dry Volume	14.0 moles/hr
H_2O	2.96 moles/hr
Total soot plus dissolved carbon	2.6 moles/hr

Table VII

(continued)

Summary of Operating Conditions and Results
For Smelting of Self-Fluxing Sinter

Independent Oxygen Balance

Input	=	Output
7.83 moles/hr	=	6.69 moles/hr

D. General Data*

Solid Carbon Consumption, lb/hr	30.5
Solid Carbon Ratio, lb/THM	~298
Total Carbon Consumption, lb/hr	134.5
Total Carbon Ratio, lb/THM	~1312
Metal Rate, lb/hr	~205

*Metal rate based on input

References

1. Masdin, E. G., and Thring, M. W., "Combustion of Single Droplets of Liquid Fuel," Journal of the Institute of Fuel, Vol. 35, No. 257, p 251, June 1902.

2. Thring, M. W., The Science of Flames and Furnaces, pp. 198, 199, 256, John Wiley and Sons, Inc., Second Edition, 1906.

3. Masdin, E. G., and Thring, M.W., ibid, pp. 254, 255.